Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/sjar
Spanish Journal of Agricultural Research 2010 8(1), 142-150
ISSN: 1695-971-X

The effect of salinity on yield and fruit quality of pepper grown in perlite

J. M. Navarro[1,2]*, C. Garrido[1], P. Flores[1,2] and V. Martínez[1]

[1] *Departamento de Fisiología y Nutrición Vegetal. Centro de Edafología y Biología Aplicada del Segura. CSIC. P.O. Box 4195. 30080 Murcia. Spain*

[2] *Present address: Instituto Murciano de Investigación y Desarrollo Agrario y Alimentario (IMIDA). C/ Mayor, s/n. 30150 La Alberca (Murcia). Spain*

Abstract

To determine the effect of irrigation with saline water (15 and 30 mM NaCl) on yield and quality of peppers, plants were grown hydroponically under greenhouse conditions in perlite, a common growing medium used for commercial cultivation. Fruits were collected in three states of maturity (green, turning and red states) and the changes in fruit quality that take place during these maturity stages were studied also, in order to find the optimal harvest time, with respect to fruit quality. With these moderate salinity levels, there was a linear relationship between NaCl concentration and reduction of the total yield of pepper. Although the number of marketable fruits was strongly reduced with regard to the total fruit number, the marketable yield did not decrease in the same proportion due to the increase of mean marketable fruit weight. Although salinity also reduced the fruit size, the number of marketable fruits was the more important cause of marketable yield reduction. The climatic conditions of the spring-summer season produced a high incidence of blossom-end rot, this being the main cause of the marketable yield reduction with the saline treatments. The red state of pepper fruits was the most appropriate since these fruits had greater firmness than turning or green fruits when cultivated under moderate salinity, as well as higher total soluble solids values.

Additional key words*:* blossom-end rot, *Capsicum annuum*, marketable yield, maturity state, total yield.

Resumen

Efecto de la salinidad en la producción y la calidad de los frutos y de pimiento cultivado en perlita

Para determinar el efecto del riego con agua salina (NaCl 15 y 30 mM) en la producción y la calidad de pimiento, se cultivaron en invernadero plantas de pimiento en perlita, un sustrato utilizado comercialmente. Los frutos se cosecharon en tres estados de maduración (verde, en viraje y rojo) y se estudiaron los cambios que tienen lugar durante estos estados de maduración en la calidad del fruto, a fin de encontrar el momento óptimo de recolección. Con estos niveles de salinidad, se encontró una relación linear entre la concentración de NaCl y la reducción de la producción total de pimiento. Mientras que el número de frutos comerciales se redujo drásticamente respecto al número total de frutos, la producción comercial no disminuyó en la misma proporción, debido al aumento del peso medio de frutos comerciales. Aunque la salinidad también redujo el tamaño del fruto, el número de frutos comerciales fue la principal causa de la reducción de la producción comercial. Las condiciones climáticas de primavera-verano produjeron una alta incidencia de pudrición apical, siendo la principal causa de la reducción de la producción comercial con los tratamientos salinos. Bajo condiciones de salinidad, el estado de maduración rojo para los frutos de pimiento fue el más apropiado, ya que estos frutos tuvieron mayor firmeza que los verdes o los que estaban virando, además de mayores valores de sólidos solubles totales.

Palabras clave adicionales: *Capsicum annuum*, estado de maduración, producción comercial, producción total, pudrición apical.

* Corresponding author: josefam.navarro2@carm.es
Received: 29-01-09; Accepted: 11-11-09.

Abbreviations used: BER (blossom-end rot), MI (maturity index), TSS (total soluble solids).

Introduction

Pepper plants (*Capsicum annuum* L.) require environmental conditions typical of southeastern Spain: high temperatures and abundant sunlight. The shortage of rain and the expansion of the area under irrigation in arid and semi-arid regions decrease the amount of fresh water and result in the intensive use of low-quality water to satisfy the increasing demand for irrigation. Pepper is an important, widespread agricultural crop in the Mediterranean area, grown commercially in semi-arid regions where salinity is a potential problem and farmers are forced to use saline water, this being the major yield-limiting factor for crops and the cause of damage to soil physicochemical properties (Biswas, 1993; Flowers, 1999). On the other hand, the market demand for peppers of high quality throughout the season has increased the growth of this crop under greenhouse, soil-less conditions. The physical properties of the substrate chosen may influence crop production and fruit quality. Perlite is a common growing medium for the cultivation of some commercial crops in Spain. However, the use of this technique for pepper crops, especially when low-quality waters must be used for irrigation, has not been studied sufficiently.

Pepper fruits can be consumed at different ripening stages (green, red or not fully-ripe). In the field, they are harvested commercially at the mature green stage (Lin *et al.,* 1993), while greenhouse-grown peppers are harvested at either the green or fully-red ripe stage (Bakker, 1989). From the point of view of the grower, a loss of harvest yield could result when immature fruits are harvested, since fruit growth continues until harvest and their size will be smaller than more-mature fruits. Besides that, harvesting fruits in the red state could be more expensive because greater amounts of water and fertilisers are needed for cultivation. On the other hand, physical and chemical attributes change during maturation and ripening and the resultant effects on fruit quality have important dietary considerations that may affect the consumption of different pepper types (Nielsen *et al*., 1991; Wall and Biles, 1993; Navarro *et al*., 2006). So, if fruits are picked when immature, they may not develop an acceptable flavour upon ripening (Boonyakiat *et al*., 1987) and this may lead to loss of consumer confidence. So, determining the optimum maturity will benefit both consumer and grower.

Little information is available on the effects of salt on greenhouse-grown pepper. It is considered sensitive (Ayers and Westcot, 1985; Cornillon and Palloix, 1995) or moderately-sensitive to salt stress (Meiri and Shalhevet, 1973; Ayers and Westcot, 1985; Rhoades *et al*., 1992). Salinity decreases pepper yield (Chartzoulakis and Klapaki, 2000; Navarro *et al*., 2002), affecting primarily the total fruit yield (above 10 mM NaCl), then the average fresh fruit weight (> 25 mM NaCl) and, finally, the number of fruits per plant (> 50 mM NaCl) (Chartzoulakis and Klapaki, 2000). The salt tolerance of pepper plants is cultivar-dependent (Chartzoulakis and Klapaki, 2000) and new commercial varieties are more sensitive to salinity than older ones (Post and Klein-Buitendijk, 1996; Navarro *et al*., 2002). In the present study, we examined the response of Orlando pepper, grown in a medium commonly used for its cultivation, to different salinity levels. Changes that take place during different maturity stages have been considered also, in order to improve the management and harvesting of this crop, with respect to minimising detrimental effects on fruit yield and maximising fruit quality.

Material and methods

Plant material and chemicals

The experiment was carried out in a greenhouse equipped with an automatic, regulated computer system for drip irrigation. California pepper hybrid cv. 'Orlando' plants obtained from a commercial nursery were transplanted (13th December) into 1.2 m-length perlite sacks. The basic nutrient solutions used for irrigation (pH 5.6) had the following macronutrient composition (mM): NO_3^-, 14; $H_2PO_4^-$, 1.5; SO_4^{2-}, 2; Ca^{2+}, 4.7; K^+, 4.85; Mg^{2+}, 2. Micronutrient concentrations were (mg L^{-1}): Fe, 1.8; Mn, 0.7; Zn, 0.12; B, 0.15; Cu, 0.07; Mo, 0.05. The plants were irrigated according to the demand detected in the appropriate trays. During the experiment, the greenhouse temperature ranged from 18 to 30°C, and relative humidity from 60 to 85%.

The experimental design consisted of three saline levels: the control, that was the basic nutrient solution, 15 mM NaCl and 30 mM NaCl. Saline treatments were reached gradually over a period of 3 days by adding the appropriate amount of NaCl to the basic nutrient solution. Fifty-four plants were distributed in the three saline treatments with three randomised blocks each, and six plants per block (18 plants per treatment). Each block was considered one replicate. Each replicate consisted of two sacks of perlite containing three 2 L h^{-1} emitters about 40 cm apart. The pH and the conductivity of the nutrient solution were controlled during each irrigation period, while the amount of nutrient solution applied depended on the demand detected in the appropriate trays.

Yield and fruit quality

Plants were harvested on 25th June. Fruits were collected at ripening (at the red stage) and the number of fruits per plant and the weight of each fruit were determined, to evaluate mean fruit weight and total fruit yield. Fruits were classified in categories, as described in Table 1. Rotten fruits and fruits with more than 20% of blossom-end rot (BER) were not taken into account for marketable yield.

During the middle of the harvest period, six uniform fruits were selected from each replicate (one per plant) for fruit quality determination. Three ripening stages were selected: green (completely-green skin), turning (approximately one-half of skin green and the other half red) and ripe (completely-red skin). The six fruits of each replicate were divided into two subgroups of three fruits each, having a total of six replicates per treatment and three fruits per replicate. Fruit pulp firmness was determined for three discs of the skin surface in the equatorial area, using a penetrometer (Bertuzzi FT 011) fitted with an 8 mm diameter probe. Fruit shape index was defined by the equatorial to longitudinal length ratio. Each fruit was washed with deionised water, rinsed free of seeds and cut in two halves. Pulp thickness was measured on three points of the equatorial area in one half of each fruit. The other half was liquefied and frozen at –20°C. For each replicate, the three fruit extracts obtained from liquefying the mesocarp were combined and centrifuged for measurements of pH, total soluble solids content (TSS), acidity and reducing sugars. The TSS in the juice was determined by an Atago N1 refractometer and expressed as °Brix at 20°C. Acidity was determined by potentiometric titration with 0.1 M NaOH, to pH 8.1, using 10 mL of juice. Results are expressed as a percentage of citric acid in the juice. Maturity index (MI) was expressed as the soluble solids/acidity ratio.

Statistical analysis

All data were analysed statistically by ANOVA and by Tukey's Multiple Range Test, to determine differences between means, using the SPSS software package (SPSS 7.5.1 for Windows, standard version, 1996).

Results

Total fruit yield per plant decreased significantly with increasing salinity, due to a reduction in fruit size (Fig. 1). Although the decrease of marketable yield observed with salinity was due to decreases in both the

Table 1. Marketable characteristics for red peppers cv 'Orlando', for categories Extra, 1, 2, 3, 4 and 5

Category	Quality	Colour	Health state	Shape	Weight (g)
Extra	Good	Uniform	Good	Square	> 225
1	Good	Uniform	Good	Square Non-square	225-200 > 225
2	Good	Uniform	Good	Square Non-square	200-160 225-170
3	Good	Uniform	Good	Square Non-square	160-115 170-125
4	Good	Uniform	Good	Square Non-square	115-90 125-100
5[a]	Industry	—	0-20% of their surface having BER	—	< 100
Non-marketable	Bad	—	> 20% of their surface having BER or rotten fruits	—	—

[a] These fruits had a least one of the characteristics described. —: these characteristics are not considered for these categories.

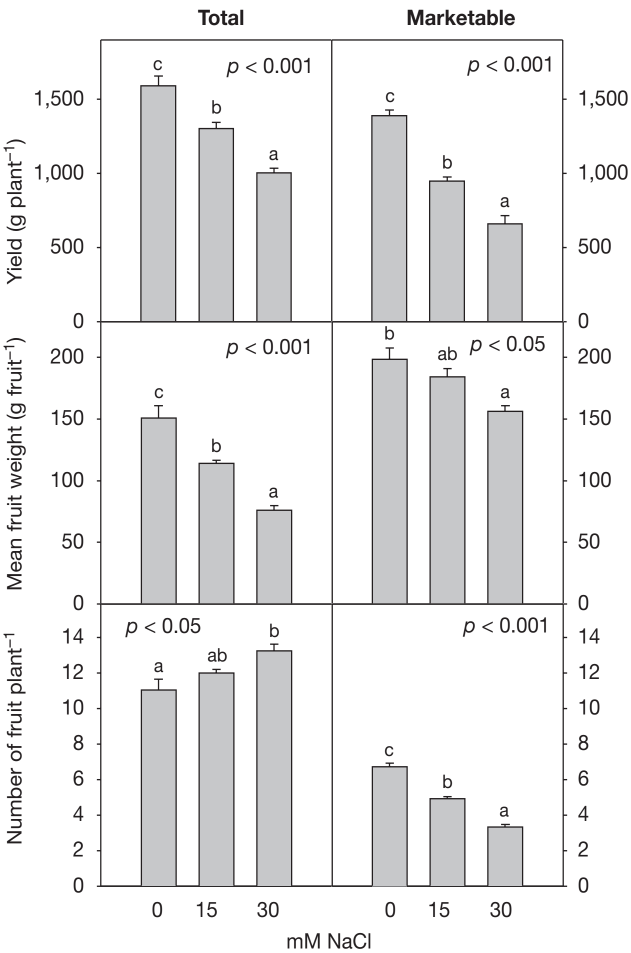

Figure 1. Effect of different salinity treatments (0, 15 and 30 mM NaCl) on yield (g plant^{-1}), mean weight (g fruit^{-1}) and number of total and marketable fruits per plant. Columns with the same letter represent values that are not significantly different at the 0.05 level of probability according to the Tukey test. Each value is the mean ± SE (n = 3).

mean fruit weight and the number of marketable fruits, the number of fruits per plant was the more important cause of this lower yield (Fig. 1). The salinity application reduced the percentage marketable yield, with respect to the total yield of the plant (Table 2). When 30 mM NaCl was applied, the weights of non-marketable fruits and fruits with BER were 34% and 32%, respectively, of the total weight.

Table 2. Marketable (Extra, 1, 2, 3, 4 and 5), non-marketable and blossom-end rot (BER) yield as percentages of the total fruit weight for plants from the 0, 15 and 30 mM NaCl treatments. Each value represents the mean of three replicates

NaCl (mM)	Marketable	Non-marketable	BER
0	87.5	12.5	6.4
15	72.8	27.2	15.4
30	65.6	34.4	32.3

For the control plants, the highest percentage of marketable fruits obtained was due to the greatest numbers of fruits being from categories 1 and 2 (Table 3), these being the heaviest fruits; the lowest percentages corresponded to categories with the lightest fruits (3, 4 and 5). The percentage of these lower categories was increased at 15 and 30 mM NaCl and, inversely, the percentages of categories extra, 1 and 2 decreased.

Marketable yield was collected mainly in the first trusses of the plant (Fig. 2); 90% of the marketable yield of control plants was obtained from the first 8 trusses, whereas this percentage of marketable yield was obtained from the first 7 and 5 trusses, respectively, for 15 and 30 mM NaCl. On the other hand, although fruits were collected until the 18th truss, all fruits harvested after the 13th, 9th or 7th truss for control, 15 or 30 mM NaCl-plants, respectively, were considered non-marketable since they had a small size or more than 20% of their surface had BER, with a low contribution to total yield.

Pulp thickness was significantly decreased by application of 30 mM NaCl. Red peppers also had lower

Table 3. Percentages of the number of fruits in marketable categories (Extra, 1, 2, 3, 4 and 5) and of non-marketable fruits, for plants from the 0, 15 and 30 mM NaCl treatments. Each value represents the mean of three replicates

NaCl (mM)	Marketable						Non-marketable
	Extra	1	2	3	4	5	
0	2.73^a	22.38^a	26.35^a	11.50	8.15^b	6.43	22.75^b
15	0.17^b	11.87^b	17.52^b	9.37	6.84^b	4.17	49.47^a
30	0.00^b	2.84^c	6.94^c	9.71	14.44^a	6.12	60.03^a
ANOVA (F values)	50***	115***	170***	ns	19**	ns	72***

** and *** represent $P < 0.01$ and 0.001, respectively. ns: not significant. Values are the mean of 6 replicates. Values followed by the same letter within a column are not significantly different at the 0.05 level of probability according to the Tukey test.

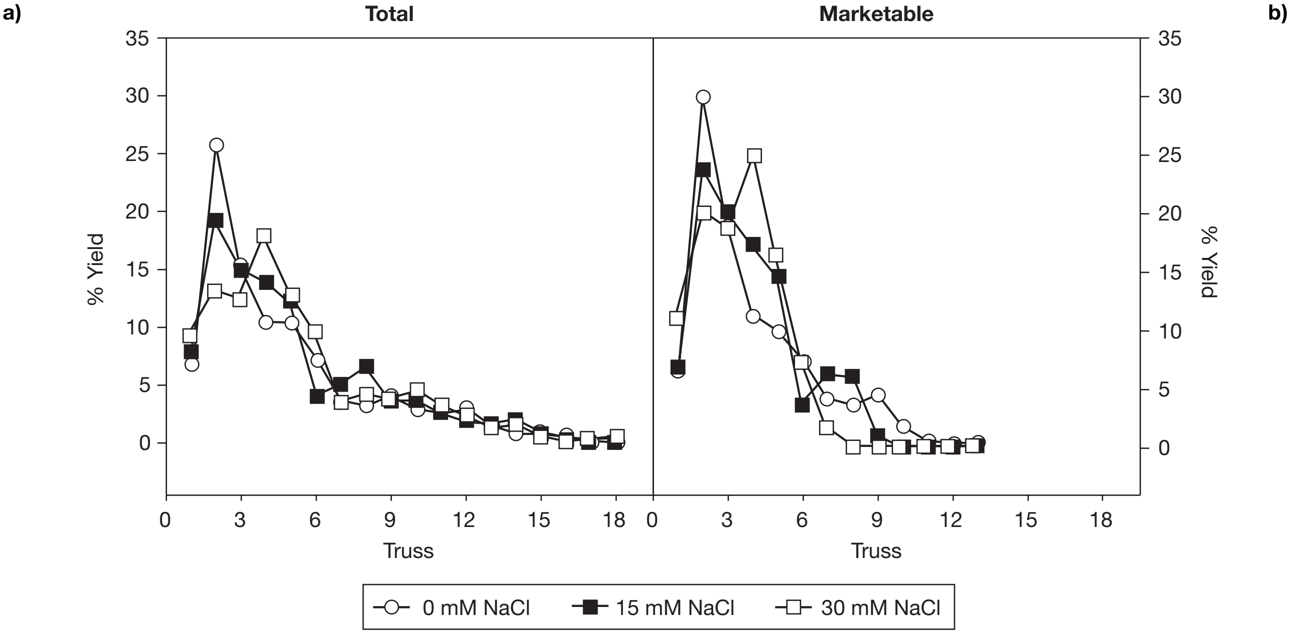

Figure 2. Contribution of each truss to the percentages of a) total fruit and b) marketable yield (fruits from Extra, 1, 2, 3, 4 and 5 categories) for the three salinity treatments (0, 15 and 30 mM NaCl). Each value represents the mean of three replicates.

pulp thickness than green or turning peppers (Table 4). The maturation of fruits had different effects on pulp firmness according to the treatments, since it increased from the green to the red state for 30 mM NaCl treatment but it was not modified for 0 and 15 mM NaCl. The shape index decreased to values near to unity with the 30 mM NaCl treatment and increased when fruits matured until the red state, with respect to the green or turning states.

Regarding the chemical quality of the fruit juice, pH, acidity and TSS were not modified significantly by salinity (Table 5); they were modified only by maturation state, that significantly decreased pH and increased acidity and TSS. A close linear relationship ($r = 0.961$, $P < 0.001$) was found between TSS and the total sugars in all fruits pepper selected for quality measurements (Fig. 3). The response of pH and acidity to salinity was dependent on the maturity state, since, for green fruits, salinity increased pH of fruit juice but a contrary effect was observed in pH and acidity of red fruits (Fig. 4). The maturity index (MI) was increased at 30 mM NaCl only in green fruits (Fig. 4) and decreased significantly with fruit maturation (Table 5).

Discussion

It has been shown that pepper salt tolerance is cultivar-dependent (Chartzoulakis and Klapaki, 2000) and new commercial varieties are more sensitive to salinity than older ones (Post and Klein-Buitendijk, 1996; Navarro *et al*., 2002). Increasing, but moderate, salinity (15 or 30 mM NaCl) reduced in a linear manner the total yield of pepper (18% and 37%, respectively) (Fig. 1), as Hirota *et al*. (1999) found previously. Although plant response to saline water can vary greatly depending, among other factors, on the specific characteristics of the plants (Barbieri, 1995), the response in this experiment of pepper, grown under commercial conditions, to moderate salinity was similar to those found in previous studies with pepper grown in nutrient solution (Navarro *et al*., 2002).

The number of marketable fruits with regard to the total fruit number was relatively low (60%) for control plants and was reduced further by salinity (to 40% and 25% for 15 and 30 mM NaCl, respectively). However, the marketable yield as a percentage of total yield was affected less by salinity, the values being 87% for control plants and 73% and 66% for 15 and 30 mM NaCl, respectively, since the mean weight of marketable fruits was increased with regard to total mean weight (24%, 38% and 51% for control, 15 and 30 mM NaCl, respectively). Salinity affected the marketable yield more than the total yield, with reductions of 32% and 53% for 15 and 30 mM NaCl, respectively. Salinity reduces total yield by a fruit size reduction (Chartzoulakis and Klapaki, 2000; Navarro *et al*., 2002) or by a decrease

Table 4. Effects of salinity (0, 15 and 30 mM NaCl) and maturity stage (green, turning and red) on the pulp thickness (mm), firmness (N mm^{-1}) and shape index on pepper fruits. Each value represents the mean of six replicates

	Pulp thickness	Firmness	Shape index
NaCl (mM)			
0	6.81^{b}	4.34	1.20^{b}
15	6.56^{ab}	4.55	1.16^{ab}
30	6.25^{a}	4.57	1.12^{a}
Maturity stage			
Green	6.83^{b}	4.43	1.09^{a}
Turning	6.48^{ab}	4.59	1.10^{a}
Red	6.31^{a}	4.44	1.28^{b}
Salinity × maturity stage			
0 mM NaCl			
Green	6.97	4.61^{ab}	1.11
Turning	6.68	4.47^{ab}	1.17
Red	6.78	3.94^{a}	1.31
15 mM NaCl			
Green	7.07	4.32^{a}	1.08
Turning	6.69	4.72^{b}	1.09
Red	5.92	4.61^{ab}	1.29
30 mM NaCl			
Green	6.45	4.36^{a}	1.07
Turning	6.08	4.58^{ab}	1.05
Red	6.23	4.76^{b}	1.25
ANOVA (F values)			
Salinity	5*	ns	5*
Maturity stage	5*	ns	44***
Salinity × Maturity stage	ns	4*	ns

* and *** represent $P < 0.05$ and 0.001, respectively. ns: not significant. Values are the means of 6 replicates. Values followed by the same letter within a column are not significantly different at the 0.05 level of probability according to the Tukey test.

in both the number and size of fruits (Meiri and Shalhevet, 1973; Gómez *et al*., 1996). In this experiment, both fruit size and the number of fruits reduced marketable yield when salinity treatments were applied, although the lower number of fruits was the main cause of this reduction. In this way, the highest number of fruits in the control treatment corresponded to categories 1 and 2, whereas saline treatments produced a higher contribution of lighter fruits (from lower categories) and a lower contribution of the heaviest fruits (Table 3).

The incidence of BER in fruits was the primary cause of marketable weight reduction with regard to the total yield (Table 2). Pepper has been described as very susceptible to BER (Bruce *et al*., 1980), with even more incidence of BER than tomato (Post and Klein-Buitendijk, 1996). Although a local deficiency of Ca during the initial stage of fruit development is widely accepted to play an important role in the induction of BER (Morley, 1996; Marcelis and Ho, 1999; Ho and White, 2005), it has also been related directly, in tomato, with the accelerated growth rate of fruits (Westerhout, 1962; Wiersum, 1966) and with light and temperature (Ho *et al*., 1993). The high incidence of BER in the control treatment (Table 2) could have been due to the climatic conditions of the spring-summer season of this experiment (high temperatures and high transpiration rates of the whole shoot). This could have caused calcium deficiency in the fruits by a decrease of the calcium influx into low-transpiring organs (Krug *et al.,* 1972), since the xylem volume flow is directed to the high-transpiring organs (Wiersum, 1966; Ho *et al*., 1993). In this way, even supplemental Ca^{2+} does not reduce BER incidence since it does not reach the fruit but is directed with the xylem flow to the high-transpiring organs (Navarro *et al*., 2005). We found that 90% of the marketable yield was obtained in the first trusses (Fig. 2), growing in April-May, whereas the latest trusses had high BER incidence since these fruits (growing in June-July) suffered higher temperatures and light intensity. The increase in the BER incidence, and consequently in the number of unmarketable fruits, with the saline treatments was probably due to the additive effects of the climatic conditions of the experiment and a calcium deficiency in the fruits caused by salinity, as shown by Adams and Ho (1992) and Ho *et al*. (1995).

Salinity had no effect on fruit firmness of peppers (Table 4) as we found in previous studies with salinity levels similar to those used in this experiment (Navarro *et al*., 2002). Some authors have found an increase of fruit firmness with fruit age (Gu *et al*., 1999; Tadesse *et al*., 2002); however, we observed a similar increase with maturation only for saline treatments and a decrease with maturation for control fruits. This must be taken into account when selecting the optimum maturation stage of the peppers for harvest, since, if saline water has been used for irrigation, red peppers are more appropriate than green ones from the point of view of better post-harvest conservation and prevention of injury by manipulation.

The responses of pH and acidity to salinity depended on the maturity state (Fig. 4). Salinity decreased pH

Table 5. Effects of salinity (0, 15 and 30 mM NaCl) and maturity stage (green, turning and red) on the pH, acidity (mg citric acid per 100 mL fruit juice), total soluble solids (TSS) (°Brix) and maturity index (MI) on the juice of pepper fruits. Each value represents the mean of six replicates

	pH	Acidity	TSS	MI
NaCl (mM)				
0	5.41	2.46	7.21	3.05[a]
15	5.34	2.54	7.34	3.11[a]
30	5.39	2.40	7.56	3.48[b]
Maturity stage				
Green	5.78[c]	1.31[a]	5.18[a]	4.02[c]
Turning	5.25[b]	2.62[b]	7.65[b]	2.95[b]
Red	5.11[a]	3.49[c]	9.27[c]	2.67[a]
Analysis of variance (F values)				
Salinity	ns	ns	ns	11***
Maturity stage	315***	672***	397***	107***
Salinity × Maturity stage	11***	4**	ns	5**

** and *** represent $P < 0.01$ and 0.001, respectively. ns: not significant. Values are the means of 6 replicates.

and increased acidity of the fruit juice for red fruits, but the contrary was observed with green fruits although the decrease of acidity was not significant. The lower pH values for NaCl-treated versus control plants found in red peppers could be due to an increase in organic acid concentrations, probably due to a higher ratio of inorganic cation/anion uptake (Davies, 1964).

An important increase of TSS was found with fruit maturity (Table 5), probably due to accumulation of sugars, since a close, positive correlation between TSS and soluble sugars, described previously for other species (Mendlinger *et al*., 1992), was found in this experiment (Fig. 3). The carbohydrate metabolism in growing fruit tissue is important in the partitioning of photosynthetically-fixed carbon in the plant, and the developing fruit is a major sink for assimilates in sweet pepper plants (Hall, 1977). Ripening physiology has considerable implication for the pattern of sugar accumulation in the fruits (Schaffer *et al*., 1989; Bognar *et al*., 1990), being different in the three phases of pepper fruit development (Nielsen *et al*., 1991). Pepper fruits could be harvested in the green, turning or red state, so the harvest time is crucial for fruit quality since hexose sugars are accumulated during ripening (Nielsen *et al*., 1991; Tadesse *et al.,* 2002) and free sugars play an important role in the flavour characteristics of fruits.

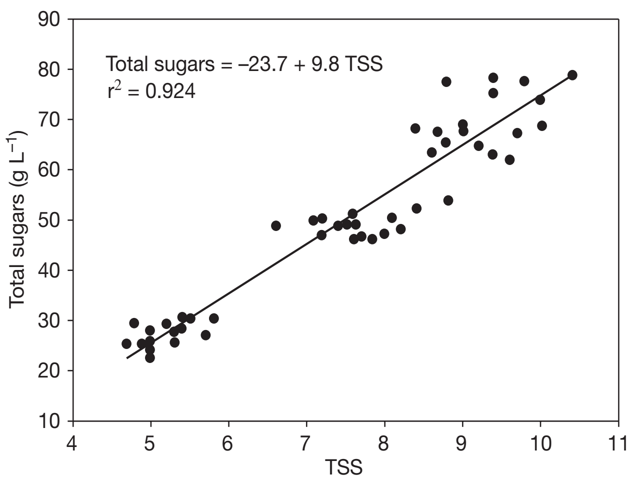

Figure 3 Relationship between total soluble solids (TSS) and total sugars found in fruits pepper grown with 0, 15 and 30 mM NaCl and harvested at three maturity stage (green, turning and red). Each point represents one replicate.

Unlike in other species, such as cucumber, melon or tomato fruits (Adams and Ho, 1989; Schaffer e*t al*., 1989; Navarro *et al*., 1999), salinity did not increase the TSS, probably due to the fruit respiration observed when the ionic strength of the nutrient solution increases (Tadesse *et al*., 1999). Previous studies on pepper fruits have found similar results for similar salinity levels (Navarro *et al*., 2002).

Although maturation increased both the TSS and acidity of pepper juice, red peppers had a lower MI than green ones, since the proportion of sugars with respect to the organic acids decreased with maturation. The salinity levels of this experiment produced no

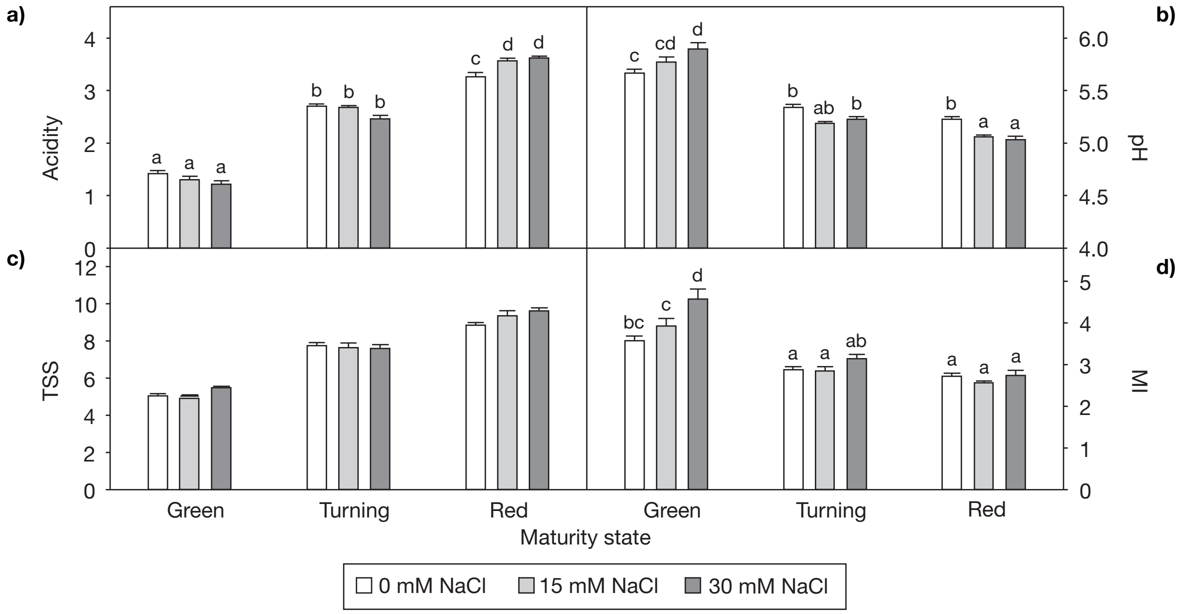

Figure 4. Effect of salinity (0, 15 and 30 mM NaCl) and maturity stage (green, turning and red fruits) on a) acidity (mg citric acid per 100 mL fruit juice), b) pH, c) total soluble solids (TSS, °Brix), and d) maturity index (MI) in peppers fruits. Columns with the same letter represent values that are not significantly different at the 0.05 level of probability according to the Tukey test. Each value is the mean ± SE (n = 6).

differences with regard to MI in turning or red peppers but increased it for peppers collected in the green state.

To summarise, we can conclude that the growth of the pepper 'Orlando' during the spring-summer period, using perlite as substrate, produced a significant decrease of pepper yield, mainly due to the high BER incidence. The use of waters of moderate salinity (15 or 30 mM NaCl) in these conditions increased the incidence of this affliction. Moderate salinity (15 mM NaCl) caused a 32% reduction in marketable yield, that could be acceptable economically in certain Mediterranean areas where only water of low quality is available. Doubling the salinity of the irrigation water, to 30 mM NaCl, resulted in a 53% reduction in marketable yield, which is considered economically unacceptable. From the point of view of the optimum harvest time, the red state is best since these peppers had the highest TSS values and the lowest maturity index; in addition, when irrigated with saline waters, they had the highest firmness values.

Acknowledgements

The authors appreciate the technical assistance of Salvador Rubio and thank Dr. David Walker for correction of the English. This work was funded by the Seneca Foundation and the Consejería de Agricultura y Agua de la Región de Murcia (project number AGR/18/FS/02).

References

ADAMS P., HO L.C., 1989. Effects of constant and fluctuating salinity on the yield, quality and calcium status of tomatoes. J Hortic Sci 67, 725-732.

ADAMS P., HO L.C., 1992. The susceptibility of mature tomato cultivars to blossom-end rot in relation to salinity. J Hortic Sci 67, 827-839.

AYERS R., WESTCOT W., 1985. Water quality for agriculture. Irrigation and Drainage. No. 29. FAO. Rome.

BAKKER J.C., 1989. The effect of air humidity on growth and fruit production of sweet pepper (*Capsicum annuum* L.). J Hortic Sci 64, 41-46.

BARBIERI G., 1995. Restrizione delle risorse idriche e strategie di irrigazione. Atti Accademie Dei Georgofili. Ser VII Vol XLII, 589-600. [In Italian].

BISWAS A.K., 1993. Water for agricultural development, opportunities and constraints. Int J Water Res Dev 9, 3-12. doi:10.1080/07900629308722569.

BOGNAR A., GOHLING H., FORTY H., 1990. Nutrient retention in chilled foods. In: Chilled foods, the state of the art (Gormley T.R., ed). Elsevier Appl Sci, London. pp. 305-321.

BOONYAKIAT D., CHEN P.M., SPOTTS R.A., RICHARDSON D.G., 1987. Effect of harvest maturity on decay and postharvest life of 'd'Anjou' pear. Sci Hort 31, 131-139.

BRUCE R.R., CHESNESS J.L., KEISLING T.C., PALLAS J.E., SMITTLE D.A., STANSELL J.R., THOMAS A.W., 1980. Irrigation of crops in the southeastern United States: Principles and practices. US Dept Agr, Sci Ed Admin Agr Rev Man ARM-S-9.

CHARTZOULAKIS K., KLAPAKI G., 2000. Response of two greenhouse pepper hybrids to NaCl salinity during different growth stages. Sci Hort 86, 247-260. doi: 10.1016/S0304-4238(00)00151-5.

CORNILLON P., PALLOIX A., 1995. Influence de la salinité et de la température du substrat sur la corissance et la nutrition du piment. Fruits 50, 469-471. [In French].

DAVIES J.N., 1964. Effects of nitrogen, phosphorus and potassium fertilizers on the non-volatile organic acids of tomato fruit. J Sci Food Agr 15, 665-673.

FLOWERS T.J., 1999. Salinisation and horticultural production. Sci Hort 78, 1-4.

GÓMEZ I., NAVARRO-PEDREÑO J., MORAL R., IBORRA M.R., PALACIOS G., MATAIX J., 1996. Salinity and nitrogen fertilization affecting the macronutrient content and yield of sweet pepper plants. J Plant Nutr 19, 353-359. doi: 10.1080/01904169609365126.

GU Y.S., HOWARD L.R., WAGNER A.B., 1999. Physicochemical factors affecting firmness of pasteurized Jalapeno pepper rings. J Food Qual 22, 619-629. doi:10.1111/j.1745-4557.1999.tb00275.x.

HALL A.J., 1977. Assimilate source-sink relationship in *Capsicum annuum* L. I. Dynamics of growth in fruiting and deflorated plants. Aust J Plant Physiol 4, 623-636. doi:10.1071/PP9770623.

HIROTA O., VILLAVICENCIO E., CHIKUSHI J., TAKEUCHI S., NAKANO Y., 1999. Effect of saline water irrigation at fruit maturity stage on transpiration rate and growth in sweet pepper (*Capsicum annuum*). J Fac Agric, Kyushu Univ, 44, 39-47.

HO L.C., BELDA R., BROWN M., ANDREWS J., ADAMS P., 1993. Uptake and transport of calcium and the possible causes of blossom end rot in tomato. J Exp Bot 44, 509-518. doi:10.1093/jxb/44.2.509.

HO L.C., ADAMS P., LI X.Z., SHEN H., ANDREWS J., XU Z.H., 1995. Response of Ca-efficient and Ca-inefficient tomato cultivars to salinity in plant growth, Ca accumulation and blossom-end rot. J Hortic Sci 70, 909-918.

HO L.C., WHITE P.J., 2005. A cellular hypothesis for the induction of blossom-end rot in tomato fruit. Ann Bot 95, 571-581. doi:10.1093/aob/mci065.

KRUG H., WIEBE H.J., JUNGK A., 1972. Calciummangel an Blumenkohl unter konstanten Klimabedingungen. Z Pflanzenernähr Dung Bodenkd 133, 213-226. [In German]. doi:10.1002/jpln.19731330304.

LIN W.C., HALL J.W., SALTVEIT M.E., 1993. Ripening stage affects the chilling sensitivity of greenhouse grown peppers. J Am Soc Hort Sci 118, 791-795.

MARCELIS L.F.M., HO L.C., 1999. Blossom-end rot in relation to growth and calcium content in fruits of sweet pepper (*Capsicum annuum* L.). J Exp Bot 50, 357-363. doi:10.1093/jexbot/50.332.356.

MEIRI A., SHALHEVET J., 1973. Pepper plant response to irrigation water quality and timing of leaching. Physical aspects of soil water and salts in ecosystems. Ecol Stud 4, 421-429.

MENDLINGER S., BENZIONI A., HUYSKENS S., VENTURA M., 1992. Fruit development and postharvest physiology of *Cucumis metuliferus* Mey, a new crop plant. J Hortic Sci 67, 489-493.

MORLEY P.S., 1996. Calcium nutrition and the physiology of sweet pepper (*Capsicum annuum* L.) fruit. PhD thesis. Leeds University, UK.

NAVARRO J.M., BOTELLA M.A., CERDÁ A., MARTÍNEZ V., 1999. Yield and fruit quality of melon plants grown under saline conditions in relation to phosphate and calcium nutrition. J Hortic Sci Biotech 74, 573-578.

NAVARRO J.M., GARRIDO C., CARVAJAL M., MARTÍNEZ V., 2002. Yield and fruit quality of pepper plants under sulphate and chloride salinity. J Hortic Sci Biotechnol 77, 52-57.

NAVARRO J.M., FLORES P., CARVAJAL M., MARTÍNEZ V., 2005. Changes in quality and yield of tomato fruits with ammonium, bicarbonate and calcium fertilisation under saline conditions. J Hortic Sci Biotechnol 80, 351-357.

NAVARRO J.M., FLORES P., GARRIDO C., MARTÍNEZ V., 2006. Changes in antioxidant compounds content in different ripening stages of pepper fruits affected by salinity. Food Chem 96, 66-73. doi:10.1016/j.foodchem.2005.01.057.

NIELSEN T.H., SKJAERBAEK H.C., KARLSEN P., 1991. Carbohydrate metabolism during fruit development in sweet pepper (*Capsicum annuum*) plants. Physiol Plant 82, 311-319. doi:10.1111/j.1399-3054.1991.tb00099.x.

POST W.H.K., KLEIN-BUITENDIJK H., 1996. Zoutonderzoek bij paprika, Invloed van natrium, calcium en kalium/magnesium verhoudingen op produktie en kwaliteit. Intern verslag PBG Naaldwijk 29, 36. [In Dutch].

RHOADES J.D., KANDIAH A., MASHALI A.M., 1992. The use of saline waters for crop production. FAO Irrig Drain, Paper 48.

SCHAFFER A.A., RYLSKI I., FOGELMAN M., 1989. Carbohydrate content and sucrose metabolism in developing *Solanum muricatum*. Phytochemistry 28, 737-739. doi:10.1016/0031-9422(89)80105-0.

TADESSE T., NICHOLS M.A., FISHER K.J., 1999. Nutrient conductivity effects on sweet pepper plants grown using a nutrient film technique 1. Yield and fruit quality. New Zeal J Crop Hort 27, 229-237.

TADESSE T., HEWETT E.W., NICHOLS M.A., FISHER K.J., 2002. Changes in physicochemical attributes of sweet pepper cv. Domino during fruit growth and development. Sci Hort 93, 91-103. doi:10.1016/S0304-4238(01)00317-X.

WALL M.M., BILES C.L., 1993. Alternaria fruit rot of ripening chile peppers. Phytopathology 83, 324-328. doi:10.1094/Phyto-83-324.

WESTERHOUT J., 1962. Relation of fruit development to the incidence of blossom-end rot of tomatoes. Neth J Agric Sci 10, 223-234.

WIERSUM L.K., 1966. Calcium content of fruits and storage tissues in relation to the mode of water supply. Acta Botanica Neerlandica 15, 406-418.